Design and RF Characterization of Spaceborne 94.1 GHz Cassegrain Dual-Reflector Cloud Profiling Radar Antenna

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INTRODUCTION: This paper presents the design and RF characterization of 94.1 GHz Cassegrain dual-reflector antenna for the proposed spaceborne Cloud Profiling Radar (CPR) instrument. The instrument is to measure the vertical cloud profile structure. The Cassegrain antenna design consists of a parabolic main reflector and a hyperboloid sub-reflector illuminated by a pyramidal feed horn as shown in Figure 1. The design specifications stipulate desired radiation characteristics (gain, sidelobe levels, and beamwidths) and maximum antenna dimension (1.85 m) for nadir looking beam. Particularly challenging in the specifications are the unique very low sidelobe levels desired at far-angle from the peak of the beam, since for a nadir pointed CPR antenna the primary source of noise/clutter is the surface return from previous pulses transmitted and received through the antenna sidelobes. It is imperative that a very accurate and real life antenna model (that includes the sub-reflector and struts blockage effects) is developed in order to be able to obtain an optimum antenna design and effectively assess and characterize its RF performance, and critically investigate the key parameters that yield far sidelobe levels reduction.

ANALYSIS: Two different models are implemented to obtain the antenna radiation characteristics. The first computational model is based on Physical Optics, PO, analysis on the main reflector and Geometrical Optics, GO, implementation on the hyperboloid sub-reflector (PO/GO) [1]. The second model is based on Physical Optics, PO, analysis on the main reflector and the application of the uniform theory of diffraction [2], UTD, on the hyperboloid sub-reflector (PO/UTD). A comparison between both methods determines the impact of diffracted fields from the edge of the sub-reflector on the antenna secondary pattern performance. Next a shadowing technique is employed to determine the effect of the sub-reflector blockage/shadowing on the radiation pattern and gain of the antenna. That is, it is assumed that the PO currents on the main reflector that fall within the geometrical optics shadow of the sub-reflector don't radiate. Hence, the PO current is set to zero in the physical optics integration in the shadow region. The effect of struts, that may be needed to support the sub-reflector, and optimum struts configurations when sub-reflector is illuminated with arbitrary polarization will be presented at the conference. This systematic analysis approach yields to determine the optimum antenna design that is allowable within the dynamic shroud of the launch vehicle.

An aperture field model is then implemented for a millimeter wave pyramidal feed horn. The model is based on the application of the Equivalent Principle. The purpose of this formulation is to determine whether a physically realizable millimeter wave pyramidal feed horn can be designed (to illuminate the sub-reflector) such that its radiation patterns match the desired $\cos^n(\theta)$ feed pattern for optimum gain, and low sidelobe levels. The $\cos^n(\theta)$ feed pattern is used as an input to the PO/UTD or PO/GO analysis.

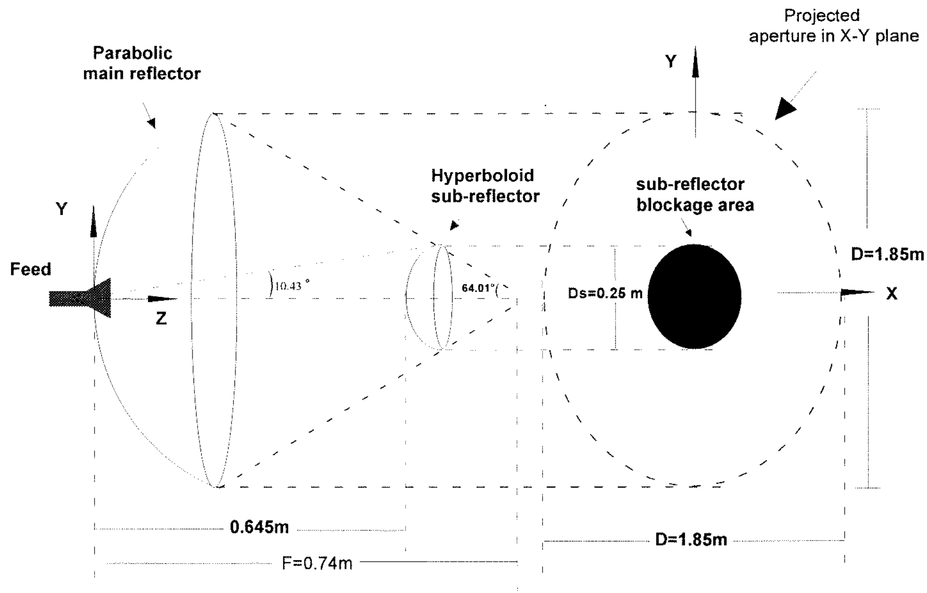
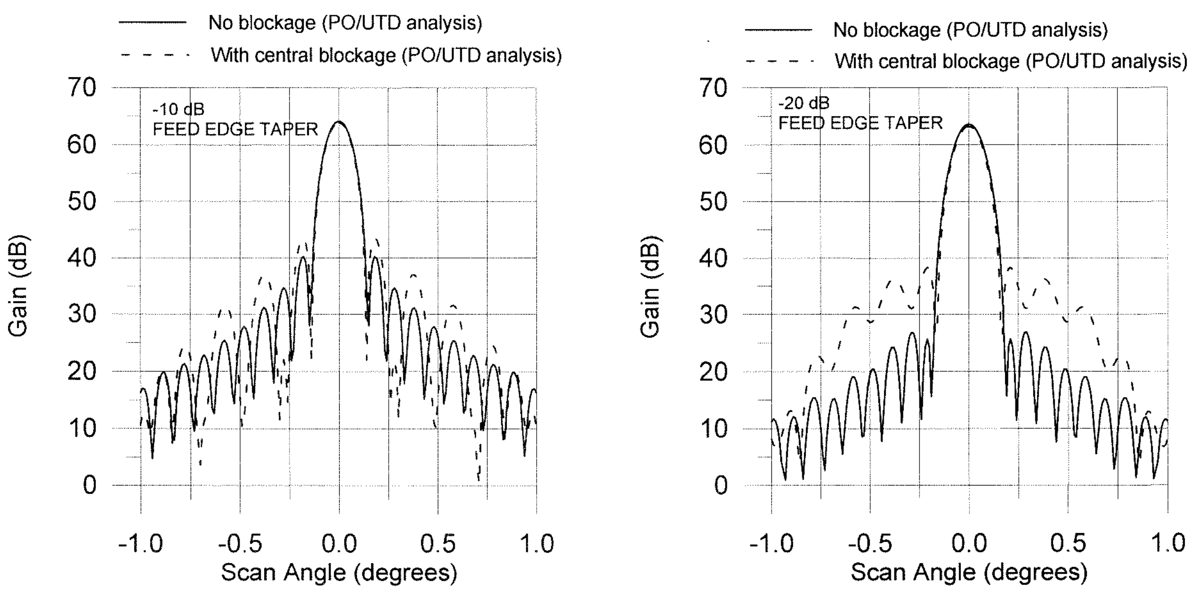


Figure 1. 94.1 GHz Cassegrain dual-reflector Cloud Profiling Radar antenna design.



(a) (b)

Figure 2. PO/UTD analysis results with and without central blockage effect for a 94.1 GHz Cassegrain dual-reflector for the design configuration in Figure 1. (a) -10 dB tapered feed illumination, (b) -20 dB tapered feed illumination.

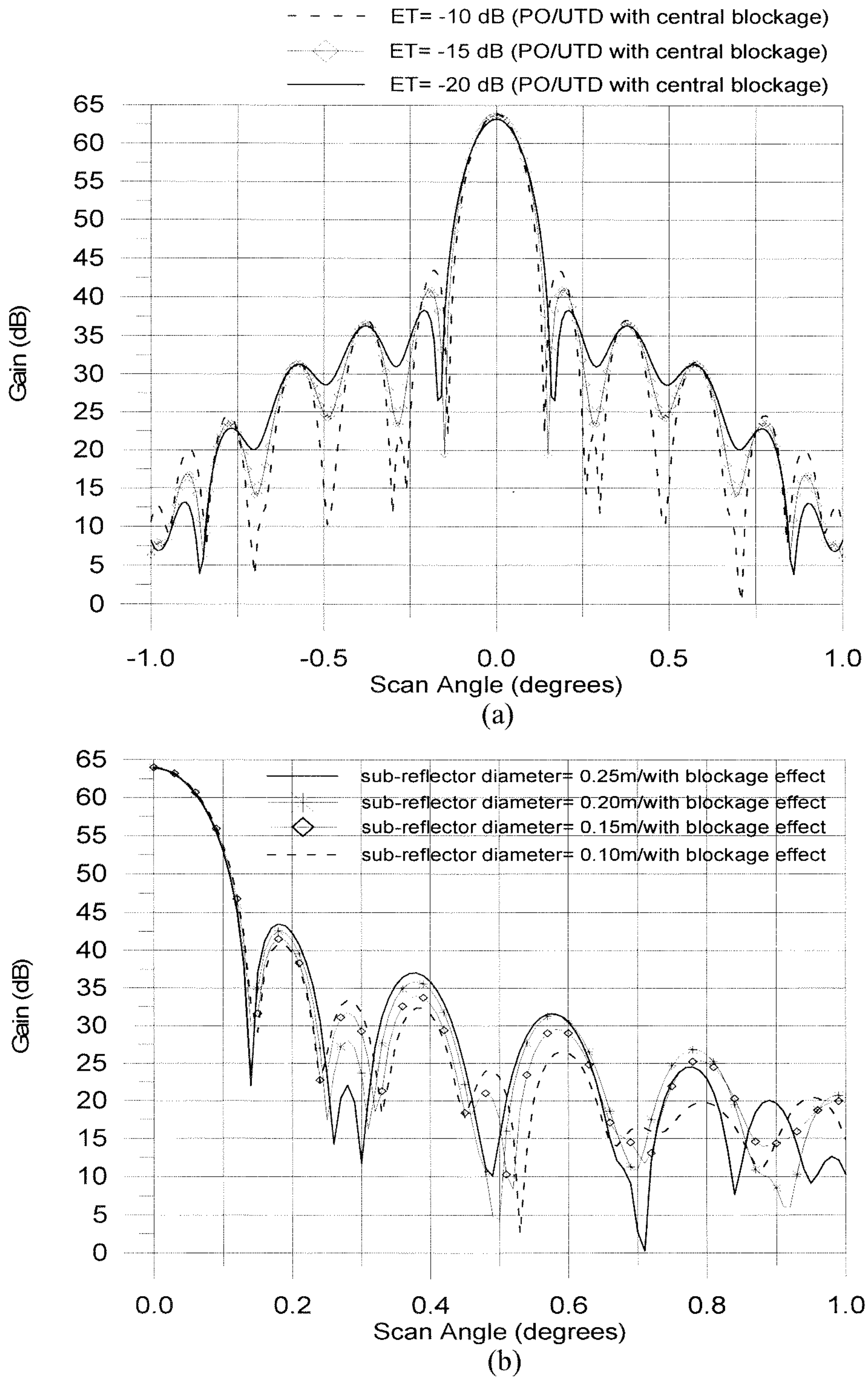


Figure 3. (a) PO/UTD antenna performance results with sub-reflector blockage/shadowing effect of 94.1 GHz Cassegrain dual-reflector for different edge tapered, ET, illumination (antenna design parameters are shown in Figure 1). (b) different sub-reflector diameter for a -10 dB tapered feed illumination for the Cassegrain antenna.

PERFORMANCE CHARACTERIZATION: A comparison between antenna patterns with and without central blockage effect for a -10 dB, and -20 dB edge taper, ET, illumination are shown in Figure 2a and b respectively. The PO/UTD blockage/shadowing results predict the loss in gain to be approximately 0.42 dB (ET=-10 dB). The peak of the first sidelobe level increases approximately 4 dB. Critical to the Cassegrain antenna design, in which very low sidelobe levels are desired, is the relationship between tapered feed illumination, ET, and antenna gain and beamwidth when the effect of the sub-reflector blockage is included in the analysis. Table 1 contains all the results of this analysis. In performing this analysis, the edge taper was varied and the resulting antenna gain, beamwidth, and radiation pattern computed. Results are shown for edge taper of -20dB, -15dB, and -10dB for the antenna configuration shown in Figure 1. As one would expect, that the maximum gain is achieved for approximately a -10dB edge taper. However, the antenna far sidelobe levels remains relatively the same for a broad range of edge taper -10 to -20 dB, with the exception of the first sidelobe level closer to the peak of the beam as shown in Figure 3a. The first sidelobe level is reduced by approximately 5 dB for edge taper range -10 to -20dB. Also note that large feed edge taper, e.g. ET=-20 dB, results in null-filling and broadening the sidelobe beamwidth as shown in Figure 2a. Similar observations were made in the extensive theoretical and experimental work on the feed-support plate blockage effect on the antenna pattern, and gain for the SeaWinds dual-beam reflector antenna [3].
For the spaceborne Cloud Profiling Radar, it is anticipated that the noise effect of the first sidelobe level on contaminating the radar cross section data can be reduced during CPR data processing. Therefore one can select the illumination edge taper (ET=-10dB) for desired maximum gain, since high feed edge taper doesn't lend itself for far-sidelobe level reduction as the general notion indicates without the central blockage/shadowing effect. Next consideration of using small sub-reflector diameter to minimize the sub-reflector blockage effect is investigated. Figure 3b shows the PO/UTD results with central blockage/shadowing effect included in the analysis for different sub-reflector diameter, and -10 dB tapered feed illumination for the Cassegrain antenna. As can be seen that the peak sidelobes levels are decreased considerably for sub-reflector diameter range 0.25 to 0.1m.

Table 1. PO/UTD Antenna performance results with sub-reflector central blockage/shadowing effect for different feed tapered illumination of a 94.1 GHz Cassegrain dual-reflector.

Feed Edge Taper Illumination (dB)	Gain (dB)	Sidelobe Level† (dB)	Beamwidth (degrees)	Sub-reflector blockage area (m^2)
-10.0	63.87	-20.4	0.112	0.049*
-15.0	63.69	-22.7	0.118	0.049*
-20.0	63.19	-25.2	0.126	0.049*

* Sub-reflector diameter is 0.25 m. † Relative to the peak of the beam.

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